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An approach of a knowledge-based process to integrate real geometry models in product simulations

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Abstract

Simulation driven product development is state of the art to insure that the desired characteristics in use behave as requested without performing a time-consuming testing using expensive prototypes. To achieve the aim of realistic and confidential results within this product simulations, a tremendous afford (i.e. when taking different non-linearities into account, like material behavior, contact situations, large deflections etc.) is necessary. Conflicting to this, the ideal CAD-model is always used for the analysis, despite knowing the effect, that every manufactured component shows differences to its ideal geometry. Within this paper an approach of a knowledge-based process to integrate real geometry data into product simulations is given. Furthermore, different methods for preparation of the simulation models are represented.

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Keywords: Computer aided design (CAD); deformation; finite element method (FEM); geometry; knowledge-based system; process; simulation; strucural analysis.

1. Introduction

Today's product development process is picking up the pace. To avoid performing complex and expensive testing methods including all iterations of the product development with a real prototype, simulation driven product development is state of the art for a functional validation of the desired characteristics. The discretization of a developed component and the use of the simulation conditions, like taking different nonlinearities (i.e. material behavior, contact situations, large deflections etc.) into account, is a tremendous effort and is mandatory to get precise and significant results.

Conflicting to this, the ideal geometry is always used for those performed analysis [1], despite knowing the effect, that every manufactured component shows differences to its ideal CAD-model. Depending on the manufacturing process various deviations may arise, e.g. spring back [2] and drapery [3] when using forming techniques or shrinkage [4] and warpage [5] when using various casting processes.

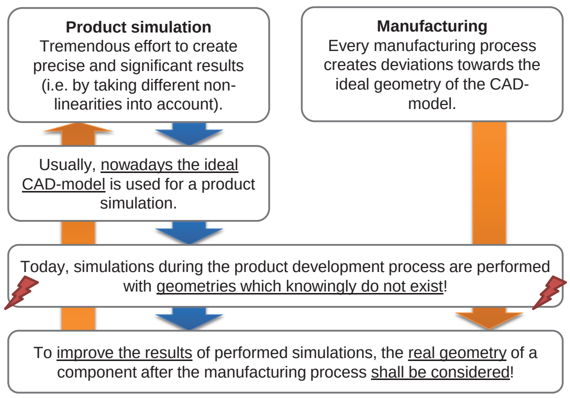

Fig. 1. Motivation to use real geometry data for simulations

It seems rather doubtful that further refinement of simulation methods makes sense, when the real manufactured geometry of the component is not considered for the simulation (refer with Fig. 1). Herein a knowledge-based

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process is presented to decide up to a certain point the ideal model can be used or when a model should be prepared with real geometry information. Furthermore, different methods for preparation of the simulation models are represented.

2. Process for the integration of real geometry models

In order to get results close to reality with performed analysis the real geometry of the component should be considered. For this purpose, the following process (refer with Fig. 2) is developed to support engineers to make a decision, whether appearing deviations are critically or not referring to the performed analysis. Therefore, a knowledge-base is deposited within this process to give all relevant information about the product, the required analysis and the manufacturing process as well as facts about the used metrology systems. Furthermore, if real geometry data should be used for simulations, depending on the progress of the development, different methods to prepare the model are proposed.

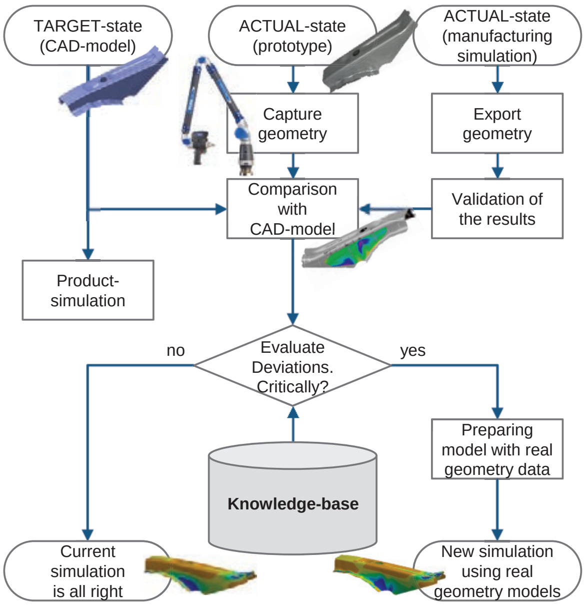

Fig. 2. Process to integrate real geometry data into product simulations

2.1. Generating the ACTUAL-state data sets

To prepare of the model with real geometry information, two ways to create the according data are possible:

- capturing the geometry using a 3D surface detection device or
- performing a simulation of the manufacturing process.

For the 3D surface detection optical devices are used basically, since they are fast, stable, relatively cheap and have a reasonable accuracy of around ±25µm [6] and even more precise.

The functionality is based on the principle of triangulation. Assuming two classes have prevailed in industrial practice:

- Laser line Scanners illuminate a laser line on the object and a camera with defined distance and angle records the deformed line. Having a relative motion between scanning system and object, in predefined distances lots of lines are detected by the camera to capture the surface of the object.
- Structured light scanning devices project a time encoded binary pattern on the object and one or more cameras detect the deformed illuminated lines on a large area at once.

Both methods create either a point cloud or a polygonal model of the object. The points only consist of three xyz-coordinates and do not bear any relation to each other. A polygonal model is created with suitable algorithms - like Delauny-algorithm [7] - from the point cloud. Both data types can be used for comparison with CAD models and are the bases for a surface reconstruction, but cannot be used directly for the generation of geometry within CAD systems.

Since every manufactured part is unique in its exact shape, it is suggested to digitalize more than one single prototype to exclude possible outliners and create a mean model of the real geometry for further work.

In addition to the 3D surface detection, it is a concern to substitute the three-dimensional surface scan of the real component with a simulated manufacturing model (for example using software by AutoForm© for sheet metal parts or Moldflow® by Autodesk® for injection moulding parts). Consequently, the engineer has the opportunity to analyse the component with real geometry data in an early phase of the product development process [8], even before there is a deformed component as a prototype at hand. Within the context of a “digital mock-up” [9], the renunciation of the real manufactured prototype has to be aspired, but still those manufacturing simulations do not have a sufficient precision compared to a real component, making a prototype currently still irreplaceable.

2.2. Knowledge-base-supported decision making

To support the design engineer in his decision, whether the occurring deviations are critically or not and consequently, whether to update the simulation model with real geometry data, a knowledge-base is implemented within the process (refer with Fig. 3). This knowledge-base consists of two main blocks:

- On the one hand side the product-specific knowledge which contains all information about a single part. Meaning the dimensional and geometric tolerances are deposited in her as well as the desired function of the component and the integration within the assembly. Furthermore, the results of comparison of TARGET- and ACTUAL-state and limits/permissible deviations of the geometric differences are stored in this block.
- On the other hand, the process-specific / general knowledge is deposited to give information about the manufacturing process with its concrete possible deviations (i.e. drapery when using the technique of deep-drawing) and the general tolerances of the process. Additionally,

information about different systems for the digitalization of prototypes can be figured out, with the explicit accuracy of every systems and if necessary of the data preparation.

- Between both blocks the analysis knowledge is located, since this is part of process-specific knowledge when performing manufacturing simulations but also product-specific knowledge with the results of product simulations, the flow of force through a component and comparative analysis of previous versions or similar parts.

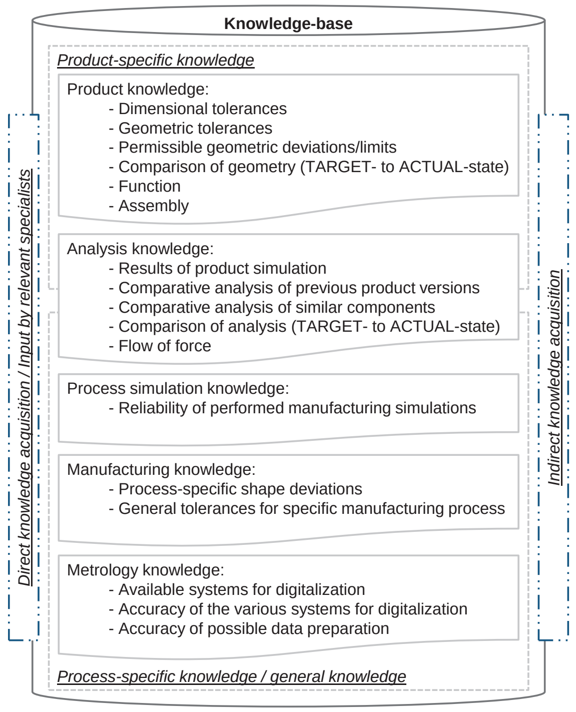

Fig. 3. Content of the knowledge-base

To fill the database with knowledge methods of direct (input by experts) and indirect (flow back from the process) acquisition are applied.

The basic knowledge is entered by the relevant specialists for each topic. For the product, the responsible product developer characterizes the dimensions, the function of the product and the position in the assembly as well as the permissible geometric deviations of the manufactured part to its ideal. The manufacturing knowledge is given by a production specialist who has a concrete idea of the occurrence of process specific deviations. Data about the use and accuracy of systems for digitalization are provided by the metrology specialists. And finally, the analysis expert / simulation engineer stores the results of product simulations and information about the manufacturing simulation where appropriate.

Besides the direct knowledge acquisition, it is the aim that the results of the presented process flow back into the knowledge base. Thereby, information about the comparison of the geometry, the analysis or analysis of similar components can create new knowledge to support the product developer finding permissible deviations for the parts for this and future product developments.

Based on the accumulated knowledge, a decision about the significance of performed analysis concerning the geometry can be made.

For this purpose of decision-making, a methodology using the information of the knowledge-base is provided to the product developer in several stages (refer with Fig. 4). Using queries, the product developer decides by means of the provided and visualized knowledge (e.g. CAD-data, simulation data, false color prints etc.) whether a model preparation is recommended or not necessary according the actual deviations.

For example, a cast component is within its dimensional tolerances, so the functionality is still provided. However, some areas show the process-specific deviation of sink marks. Finally, if stresses within the structural analysis with the ideal model are high in those areas, it is recommended to prepare the model with real geometry data.

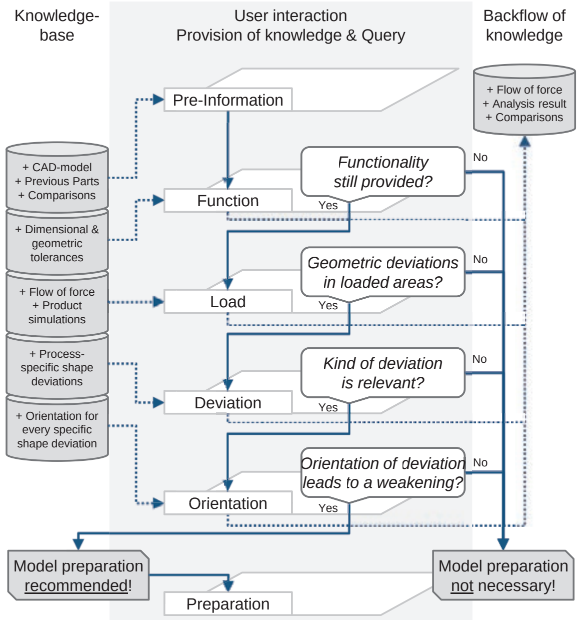

Fig. 4. Methodology of decision-making within the process

2.3. Approaches to update the simulation model with real geometry information

When the evaluation of the occurring deviations finally shows that the differences of the real model compared to the CAD-model are relevant for performing simulations, the knowledge-based process provides various methods to prepare the ideal simulation/CAD-model with real geometry data (refer with Fig. 5).

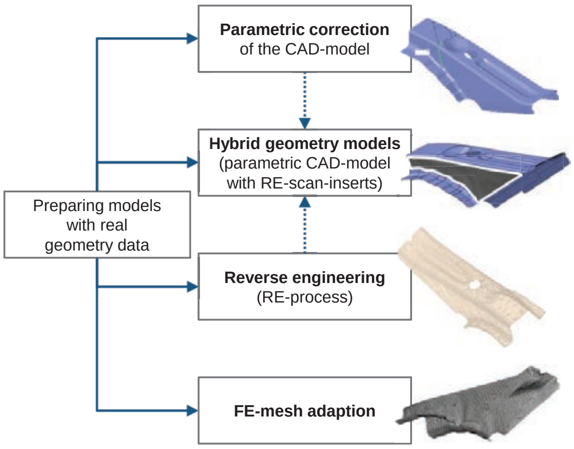

Fig. 5. Provided approaches to prepare the simulation model with real geometry data

Whenever possible, the parametric of a CAD-model should be maintained to keep the product model consistent through the product development process. To achieve this, the first suggested method to prepare the model is to modify the parameters of the design CAD-model. Therefore, regular geometry elements (i.e. plains, cylinders or cones) could be extracted from the model and the ACTUAL-state of those elements can be measured. The value of the measurement is returned to the CAD system and the real shape can be created.

The main disadvantage of this method is that only simple manufacturing deviations, like the wrong angle at a bending process through spring back, can be corrected. Complex deviations, for example drapery from deep-drawing manufacturing, would be very hard to reproduce with design features within a CAD system. Besides this, a parametric model is not always at hand. In most cases for a supplier just data, which meet the requirements for neutral data formats [10], like STEP [11] or IGES [12], are available, since almost every OEM wish to disclose any company knowledge of the product. Therein are the limitations of this method.

Assuming an off tool part with systematic errors is at hand, reverse engineering (RE) describes a procedure of returning the real existing shape of the component into a CAD-model [13]. The process of RE is a generic process [14] and essentially includes three steps [15]:

- It starts with the digitalization of a component to a point cloud, an accumulation of single points with xyz-coordinates baring no relationship to each other.
- Within the second step a data preparation of the point cloud follows. Herein the postprocessing of the scan data is frequently required (this implies smoothening surfaces, closing holes from undetectable areas or manual deleting of wrongly captured areas through noise or mounting brackets). Furthermore, the creation of a polygonal model is located here.
- The third and last step comprises the reconstruction into a CAD surface model. Therefore, the polygonal model has to be segmented into four-sided areas. Each area will be described as one surface patch later. A standard for a mathematical surface description is by using NURBS surfaces. These surface patches offer an exact description for both, analytical standard forms and free-form surfaces. Other advantages of NURBS-patches are: a relatively small memory usage, because only control points, grid and knot vectors have to be saved, as well as the speed and numerical stability of NURBS-algorithms [16].

The surface reconstruction, in general, is a very complex and time-consuming part of the RE process. Approximately 80% or even more of the total time in reverse engineering is often used for segmenting and reconstructing the polygonal model to surfaces [17].

To combine the advantages of both previous mentioned methods, on the one hand the use of parametric CAD models and on the other hand the general validity, general usability and flexibility of a surface reconstruction, an approach to create hybrid geometry models for simulations was made [18]. These hybrid models result from the parametric CAD-models for the most areas of the part, but areas with large or complex deviations are substituted by scan-inserts (refer with Fig. 6). Those inserts consist of surface reconstructed NURBS-patches based on the recorded data set of a real components 3D surface scan. Using this procedure, the amount of data - compared to the scan model - and the time for model preparation can be reduced to a minimum.

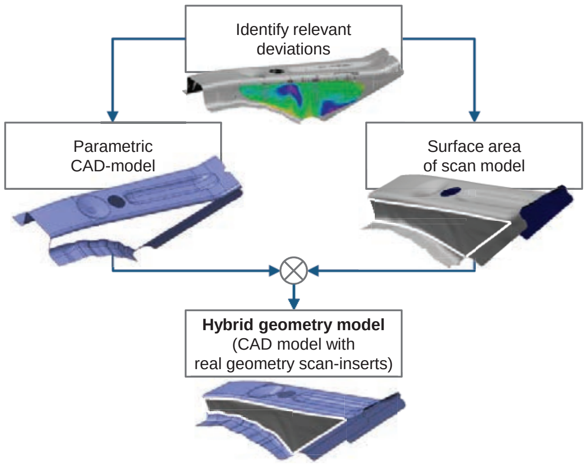

Fig. 6. Strategy of creating hybrid geometry models

Another approach to use real geometry elements in simulations appears, when an FEA (finite element analysis) already exists. The FE-mesh adaption uses the present mesh, based on the non-deformed CAD geometry and adapts it to the data of the 3D surface scan [19]. The advantage can be seen in the omission of a complex design of a new model for simulating the real geometry. Thus, this method is applied, when an FE simulation with ideal geometry is performed already.

Within this algorithm the deviations at the every surface node towards the scanned geometry data (either point cloud or polygonal model) is measured. Those deviations are applied as displacements using a preload step to the actual analysis [20]. The resulting mesh is finally used for the actual simulation with real geometry (refer with Fig. 7).

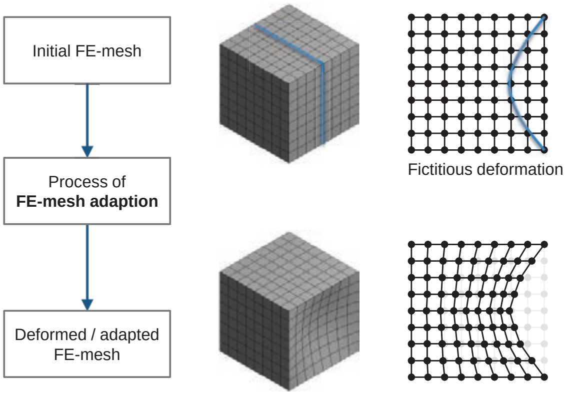

Fig. 7. Basic functionality of the FE-mesh adaption

3. Future work: implementation as software demonstrator

The main task for the future is the implementation of the described knowledge-based process to integrate real geometry models into simulations in a software demonstrator. Therefore, the idea is to use the ANSYS® Engineering Knowledge Manager (EKM) , since it "[…] provides an open collaboration platform for simulation IP management" [21, 22]. Within this software you can store the explicit knowledge and get access to the situational knowledge when needed. Additionally, the workflow can be created and managed with a graphical interface. Furthermore, it enables common visualization for various CAD/CAE data types.

Fig.8 shows the partial implementation into the operational demonstrator using ANSYS EKM.

Finally, the process shall be validated exemplarily within an industrial partner using the specific knowledge of the intern specialists with their belonging to the firm products, manufacturing techniques and processes.

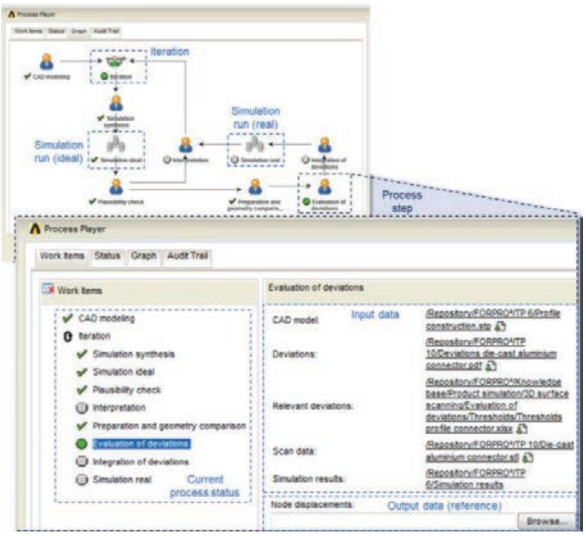

Fig. 8. Mapped simulation processes and dialogue component to evaluate and integrate deviations [23]

4. Summary

To sum up, almost every produced component differs in its geometry compared to the ideal model of the CAD-system. Those deviations due to the production process can trigger various influences on the results of performed analysis. To identify and evaluate these differences of TARGET- and ACTUAL-state the presented knowledge-based process is developed. Within this process a knowledge-base supported decision can be made, whether a performed simulation/analysis returns applicable results or not. If it is suggested, to use real geometry data for the simulation due to relevant deviations of the manufactured component towards the ideal CAD-model, different ways of updating the model - depending on preliminary work - are provided.

Concluding it can be pointed out, that this process can help to increase the efficiency of the virtual product development through the use of real geometry data and the knowledge when and how to use it.

Acknowledgements

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